FORMATION OF THE FUNDAMENTAL MODE OF A XeCl–LASER WITH UNSTABLE TELESCOPIC RESONATOR FORMED BY A PARTIALLY REFLECTING OUTPUT MIRROR

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The results of experimental investigation of a XeCl laser, in which a resonator formed by a concave mirror and a partially reflecting convex specular meniscus is used to decrease the output beam divergence, are presented.

It is shown that the optimal reflectance of the specular meniscus at magnification $M = 10$ equals 20% for this laser. Based on numerical calculations, it is concluded that this laser with a plane–parallel resonator, whose output mirror is a quartz plate, and with an unstable telescopic resonator at magnification $M = 10$ being formed by totally reflecting mirrors, operates under conditions of saturation. In the first case, the optimal reflectance of the output mirror is equal to 4.5%, and in the second case, the optimal magnification of the resonator is $M = 22$.

The problem of decreasing the beam divergence of exciplex lasers based on inert gas halides is one of the most important problems which must be solved in order to extend the range of applicability of these high–power and efficient sources of UV radiation. Unstable telescopic resonators, in which the output beam passed by the convex mirror M_2, are most widely used for this purpose (Fig. 1*a*).[1,2]

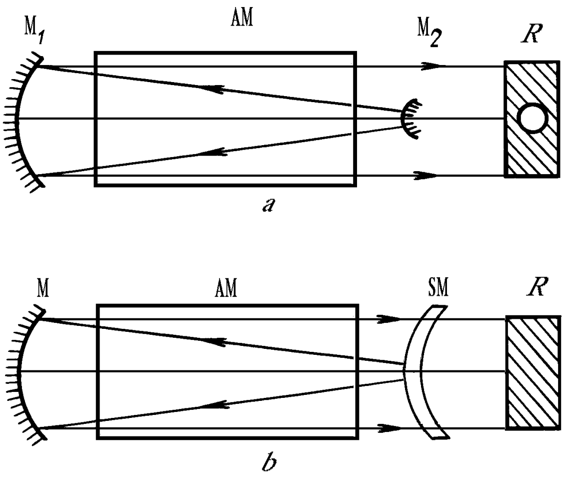

FIG. 1. The optical scheme of the XeCl laser with unstable telescopic resonators in which the output beam passed by the convex mirror M_2 (a) through the partially reflecting specular meniscus SM (b): M and M_1 are the concave mirrors of the resonator; AM is the active medium; and R is the output cross section of the laser beam.

We, in particular, employed a resonator formed by a totally reflecting concave mirror *M* and by a partially reflecting specular meniscus (*SM*), whose reflectance varied from 10 to 40% (Fig. 1*b*). Such a resonator is rarely employed, though it has a number of advantages, such as a lower intensity of superluminescent background and a more homogeneous intensity distribution over the beam cross section as in Ref. 3, but with smaller losses due to the optical parts, as well as a simpler technology of deposition of the coating onto the output mirror. The disadvantages of this resonator include the losses due to the reflection of the output beam with a planar wave front (because the reflecting coating is deposited onto the entire surface of the mirror) and the beam reflection from the output mirror and from the electrodes which gives rise to the idler waves and may affect the diffraction–limited beams. In this paper we compare the output beam characteristics of the laser with a standard unstable telescopic resonator and with the above–described resonator.

The laser setup consisted of an electric discharge unit[4] with $2\times0.6\times70\ cm^3$ discharge, where $d = 2$ cm was the interelectrode gap. The peak pumping power density was about 2–3 MW/cm^3 for the 20 ns pulse width at half–amplitude. The mixture Xe:HCl = 5:1 (4 mm Hg) with buffer gas Ne was excited at a pressure of 3 atm. Previously we measured the amplification coefficient under such pumping conditions and it was about 0.15 cm^{-1}. The unsaturated absorption coefficient, in accordance with Ref. 5, was equal to 0.008–0.01 cm^{-1}. The resonator was formed by a concave mirror with radius $R = 200$ cm and reflectance $\rho = 95\%$ at the wavelength $\lambda = 308$ nm and by a convex specular meniscus with $R_{SM} = 20$ cm, $\rho_{SM} = 12$, 20, and 40%. The distance between these mirrors, which served as the laser–cell windows, amounted to 83.5 cm. The resulting output beam had a wavefront which was close to the planar wave front, the focusing point was located at the distance

$$l = (M + 1)\, L^2/(M - 1)\, d = 24 \text{ m},^6\ d = \left| \frac{R}{2} - \frac{R_m}{2} - L \right| .$$

The beam divergence was determined by photometric measurements of the negative of the focal spot photographed on a RF–3 film when the laser beam was focused with a lens with focal length $F = 32.4$ cm. We also measured the fraction of radiation energy with one or another divergence using a collection of diaphragms. An opacity density records of the light intensity distribution over the focal spot formed with the lens is given in Fig. 2 for the resonator with $\rho_{SM} = 20\%$ (in the direction parallel to the discharge field).

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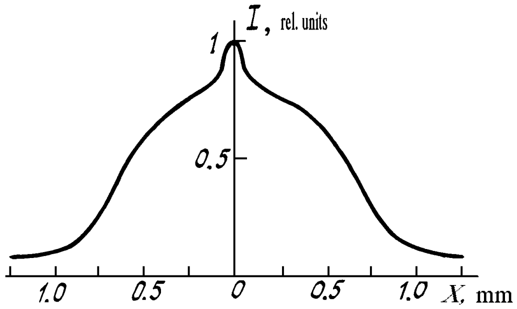

FIG. 2. The opacity density record of the focal spot of the laser beam formed by the concave mirror––specular meniscus resonator with $\rho_{SM} = 20\%$ *at* $M = 10$*. The focal length of the lens* $F = 32.4$ *cm.*

It can be seen that the focal spot is a superposition of two cores with divergences of ~ 4 and 0.4 mrad. The distribution wings are caused by a superluminescent background with a divergence of ~ 30 mrad. The same pattern was observed in Ref. 3 and was associated with the gradual decrease in the beam divergence when the number of beam passages round the resonator is increased. Indeed, after N passages of the beam its divergence is:[6]

$$\theta_N = \frac{d}{L_{dis}\,M^{N-1}}\,(1 - 1/M)\ ,$$

where L_{dis} is the discharge–gap length and d is its transverse size (e.g., the interelectrode distance). The diffraction–limited divergence $\theta_{dif} = 2.44\ \lambda/d$ of the beam is attained after N_0 passages given by the relation

$$N_0 = \ln\,[4\,(M - 1)d^2/\lambda L_{dis}]/\ln M\ .$$

If the laser–pulse oscillogram is known, then, knowing the time required for the beam to pass around (the distance $2L$), we can calculate the fraction of the beam energy which will have such a divergence. For the case under consideration we have $M = 10$, $L_{dis} = 70$ cm, $L = 83.5$ cm, and $\lambda = 308$ nm. Now, after two passages (after a time $\tau_2 = 4L/c = 10$ ns), the radiation will have the divergence $\theta_2 = 4$ mrad and the energy of the beam with such a divergence will comprise

$$\frac{\int_0^{\tau_2} P\,\mathrm{d}\tau}{\int_0^{\tau_r} P\,\mathrm{d}\tau} \gg 50\%$$

of the total beam energy (P is the laser beam power). After three passages $\theta = 0.4$ mrad and the energy fraction is equal to ~ 30%. The diffraction–limited divergence is attained by the pulse termination for $N_0 = 4$ and the energy of such a beam comprises less than 10% of the total energy. Note that our data show that when the diffraction limit (θ $5\theta_{dif}$) is approached, the results of calculations increasingly worse agree with experiment, because the beam formation starts being affected by the discharge nonuniformities, the idler waves reflected from the plane faces of the optical parts, etc. In the numerical calculations the mirrors were assumed to be totally reflecting. However, if the output mirror reflects partially, then the fundamental mode will be separated out by a factor of $1/\rho_{SM}$ slower and without saturation.

TABLE I. The total laser output energy E_t *and the energies* E_{θ_2} *and* E_{θ_3} *of beams with the divergences* θ_2 *and* θ_3 *for three different reflectances of the specular meniscus* ρ_{SM} and *plane–parallel and standard unstable telescopic resonators with* $\rho_1 = \rho_2 = 100\%$.

ρ_{SM}, %	E_t, mJ	E_{θ_2}, mJ	E_{θ_3}, mJ
12	28	12	5
20	30	15	10
40	24	12	7
PPR	54	–	–
UTR	20	11	6

Table I gives the total output energy of the laser and the energies of beams with the divergences θ_2 and θ_3 for three different reflectances of the specular meniscus. For comparison, data for the plane–parallel and standard unstable resonators are also tabulated. It is evident that for $\rho_{SM} = 12\%$ the rate of separation of the fundamental mode slows down in comparison with that of the standard unstable telescopic resonator. However, starting with $\rho_{SM} = 20\%$, the fraction of the beams with divergences 4 mrad and 0.4 mrad is no longer dependent on ρ_{SM}, while the total energy decreases with ρ_{SM}. Thus, the saturation of amplification is observed. It is well known[5] that the maximum intensity of the laser beam I_{max}, which can be taken from an aperture unit neglecting the losses, is given by the relation

$$I_{\rm max} = g_0 L_{dis} I_{\rm s}\ ,$$

where g_0 is the coefficient of amplification of the weak signal and I_s is the intensity of saturation. Let us imitate this situation as follows. Let us assume that the amplification coefficient remains unchanged so far as $I \sim I_{max}$ is not attained and then abruptly drops to zero. In this case the beam will pass the remaining part of the path with absorption coefficient α (unsaturated absorption coefficient). This approximation is quite adequate when g_0 10α and is valid in our case. Now, the distance passed by the beam with absorption up to the exit from the active medium is given by the relation

$$L_{\rm n} = \frac{\ln I_{\rm max}/I_{\rm utr}}{\alpha} \approx 30\ \text{cm}$$

for $I_{\rm utr}$, corresponding to the standard unstable telescopic resonator, $g_0 = 0.12\ \text{cm}^{-1}$, $I_s = 0.25\ \text{MW/cm}^2$ (Ref. 5), $L_{\rm dif} = 70$ cm, $\alpha = 0.008$ cm, and $I_{\rm utr} = 1.8\ \text{MW/cm}^2$. The beam must pass the same distance to attain the same I when the output mirror reflectance is ρ_{SM} and, therefore, the initial intensity is by a factor of $1/\rho_{SM}$ lower than before if $\rho_{SM} = 20\%$. Thus, $\rho_{SM} = 20\%$ is the optimal reflectance of the output mirror for the laser with the above–indicated parameters of the active medium. From this it follows that under conditions of short and powerful pumping of an exciplex laser (e.g., pumping by fast discharge) and large active length, first, it is not obligatory to use totally reflecting mirrors to form the unstable telescopic resonator. This leads to an improvement of the spatial homogeneity of the beam without deterioration of the other laser parameters. Second, the feedback coefficient in the plane–parallel resonator is $(1/M^2) \cdot \rho_{SM} = 4.5\%$. So it is smaller than in the case in which an uncoated quartz plate is placed at the exit. Therefore, in some cases it is necessary that a bleaching coating be deposited on the plate in order to increase the output energy of the laser. Finally, for the unstable resonator with totally reflecting mirrors the optimal, from the viewpoint of feedback, magnification equals 22. It is obvious that employment of such a magnification in the resonator formed by a concave mirror and specular meniscus is not advisable owing to high losses for the beam reflection from the output mirror. If the magnification factor M increases between 10 and 22, the beam quality improves and its energy decreases. The optimal magnification factor equals 15–16..

To summarize, experimental investigations allow us to draw the following conclusions:

1. The resonator formed by a concave mirror and partially reflecting specular meniscus possesses indubitable advantages over the standard unstable telescopic resonator in order to attain a divergence of $\sim 5 - 10\,\theta_{dif}$, i.e., $100 - 500$ μrad.

2. Under conditions of short high–power pumping and large active length, the optimal feedback coefficient of a plane–parallel resonator may be obtained for a quartz plate with bleaching coating.

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